Effects of Calcium, Available Phosphorus and Microbial Phytase on Ovarian FSHR and LHR Expression in Laying Hens

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ABSTRACT: Folliculogenesis, steroidogenesis, ovulation, and vitellogenesis are regulated by the effect of follicle stimulating hormone (FSH) and luteinizing hormone (LH) in the hypothalamus-pituitary-ovary axis and these hormones act via follicle stimulating hormone receptor (FSHR) and luteinizing hormone receptor (LHR) in the ovary. Poultry ration and food additives are essential in the regulation of reproductive activity. Phytase is a supplement frequently added to laying hen diets to increase phosphorus (P) utilization. The aim of this study was to reveal the effects of a newly isolated microbial phytase together with different concentrations of calcium (Ca\textsuperscript{2+}) and available phosphorus (AP) on ovarian FSHR and LHR expressions. For this purpose, 90 Lohmann LSL-White layers were first divided into three main diet groups (standard Ca\textsuperscript{2+} and AP, standard Ca\textsuperscript{2+} and low AP, low Ca\textsuperscript{2+} and AP) and then into three subgroups (no-phytase, commercial phytase, and microbial phytase). At the end of the experiment, all chickens were slaughtered and ovarian tissues were fixed in formalin. Routine avidin-biotin complex immunohistochemistry was performed using anti-FSHR and anti-LHR primary antibodies. Immunohistochemically, FSHR and LHR were expressed in granulosa/theca cells, oocytes, interstitial cells, and vitellus. While the expression intensity of the receptors increased in the microbial phytase-treated groups, the strongest expression was obtained in the granulosa/theca cells and oocytes in the standard Ca and low AP group. In conclusion, we suggest that the addition of newly isolated microbial phytase to diets of laying hens and feeding standard Ca and low AP may have positive effects on reproductive performance by increasing the FSHR and LHR expression in ovaries.

Keywords: available phosphorus; calcium; FSHR; microbial phytase; LHR
INTRODUCTION

Reproductive activity and egg-laying performance in poultry are regulated by the hypothalamus-pituitary-ovarian axis as in mammals (Mishra et al., 2020). Follicle stimulating hormone (FSH) and luteinizing hormone (LH) from the anterior pituitary act on the gonads and induce gametogenesis, steroidogenesis, and ovulation in females via receptors FSHR and LHR in ovarian follicle granulosa and theca cells (Grzegorzewska et al., 2009). One of the factors affecting reproductive hormone secretion and regulation in poultry is diet content (Colin et al., 2020). Calcium (Ca\(^{2+}\)) and phosphorus (P) are macro minerals and are involved in metabolic activities, eggshell formation and quality, hatchability, specific gravity, and laying performance essential for poultry production (Keshavarz and Nakajima, 1993; Jiang et al., 2013). A decrease in the absorption of Ca\(^{2+}\) and P from the intestines due to reduced amounts of Ca\(^{2+}\) and P in the diet or diseases such as Newcastle causes decreased blood serum level and affects egg production and quality (Igwe et al., 2018).

A significant portion (50-80%) of P is in the form of phytic acid, which is degraded with the phytase enzyme available in very limited amounts in the digestive system of poultry (Gordon and Roland, 1998). Insufficient digestion of P generates two crucial negative consequences; (i) pollution occurs as a result of enrichment of soil and surface waters with quite a high P-rich faeces, (ii) production costs increase through the addition of expensive inorganic phosphorus sources (Abbasi et al., 2019). A solution to these negative situations is the addition of phytase to the rations exogenously (Jalal al., 2014; Bello et al., 2020). Calcium (Ca\(^{2+}\)) and phosphorus (P) concentrations of laying hens. We investigated how microbial phytase (MP) affects the expression of FSHR and LHR in the ovary under diverse dietary conditions.

MATERIALS AND METHODS

Housing and management

The research was conducted at the Poultry Unit of Bursa Uludag University, Research and Application Farm after the approval of the Bursa Uludag University Animal Research Local Ethics Committee (2021-07/05). Ninety, second term Lohmann LSL-White laying hens were housed in three-tier California-type poultry cages with nipple drinkers. The light was available as 16 hours lighting:8 hours darkness and feeding was ad libitum group feeding.

Diet and treatments

Table 1. contains the content of the diet. The method reported in Association of Official Agricultural Chemists (AOAC) International was used for the nutrient analysis of the feed ingredients and mixed rations used in the preparation of the diets (AOAC, 2000) and the starch content was determined according to a previously reported method (Bal et al., 2000). The metabolizable energy levels were calculated using the formula developed by the Turkish Standardization Institute.

The chickens were randomly distributed into three treatments.

<table>
<thead>
<tr>
<th>Ingredients</th>
<th>g/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn (7.5% CP)</td>
<td>565.70</td>
</tr>
<tr>
<td>Soybean meal (44% CP)</td>
<td>50.00</td>
</tr>
<tr>
<td>Full fat soybean</td>
<td>177.00</td>
</tr>
<tr>
<td>Corn gluten</td>
<td>50.00</td>
</tr>
<tr>
<td>Sunflower meal</td>
<td>30.00</td>
</tr>
<tr>
<td>Limestone</td>
<td>97.00</td>
</tr>
<tr>
<td>Dicalcium phosphate</td>
<td>19.50</td>
</tr>
<tr>
<td>Salt</td>
<td>2.50</td>
</tr>
<tr>
<td>Vitamin-mineral premix*</td>
<td>3.50</td>
</tr>
<tr>
<td>DL-methionine</td>
<td>1.00</td>
</tr>
<tr>
<td>L-lysine HCl</td>
<td>1.00</td>
</tr>
<tr>
<td>Sodium bicarbonate</td>
<td>1.00</td>
</tr>
<tr>
<td>Choline chloride</td>
<td>0.80</td>
</tr>
<tr>
<td>Antioxidant</td>
<td>1.00</td>
</tr>
</tbody>
</table>

**Analysed concentration**

<table>
<thead>
<tr>
<th>Metabolizable energy, kcal/kg</th>
<th>2793</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crude protein</td>
<td>173.00</td>
</tr>
<tr>
<td>Calcium</td>
<td>42.00</td>
</tr>
<tr>
<td>Available phosphorus</td>
<td>4.30</td>
</tr>
<tr>
<td>Sodium</td>
<td>1.70</td>
</tr>
<tr>
<td>Lysine</td>
<td>8.30</td>
</tr>
<tr>
<td>Methionine</td>
<td>4.10</td>
</tr>
<tr>
<td>Threonine</td>
<td>5.70</td>
</tr>
</tbody>
</table>

*: 3.5 kg premix contains 10,000,000 IU vitamin A; 2,500,000 IU vitamin D3; 20,000 mg vitamin E; 3,000 mg vitamin K3; 1,000 mg vitamin B1; 4,000 mg vitamin B2; 3,000 mg vitamin B6; 25 mg vitamin B12; 22,500 mg niacin; 10,000 mg calcium D-pantothenate; 500 mg folic acid; 50 mg biotin; 400,000 mg choline; 100,000 mg Mn; 25,000 mg Fe; 60,000 mg Zn; 5,000 mg Cu; 200 mg Co; 500 mg I; 200 mg Se.
diet groups as (i) standard levels of Ca\(^{2+}\) and standard levels of available phosphorus (Ca\(^{2+}\)+AP), (ii) standard levels of Ca\(^{2+}\) and low levels of AP (Ca\(^{2+}\)+low AP), (iii) low levels of Ca\(^{2+}\) and low levels of AP (low Ca\(^{2+}\)+low AP). Each diet group had three phytase subgroups as without phytase (Phy-), commercial phytase (CP), and microbial phytase (MP).

A total of 300 FTU/kg dose of the commercial phytase (6-phytase derived from *E. coli*) or microbial phytase (3-phytase derived from *Bacillus megaterium* EBD9-1, isolated from the soil of Trabzon province in Turkey) were added to the relevant diets. Phosphorus was available as 0.10% in a diet containing 300 FTU/kg phytase. The same amount of phytase was added to 1 g/kg matrix value for Ca\(^{2+}\). The calcium and AP levels in the Ca+AP-containing groups were arranged to be 4.20% and 0.43%, respectively, whereas in the low Ca+low AP diet groups these values were 4.10% and 0.33%, respectively.

**Histomorphology and immunohistochemistry**

Birds were slaughtered at the end of the experiment and ovarian samples were fixed in 10% neutral buffered formalin. After routine histological procedures, ovarian tissues were embedded in paraffin. Five μm thick sections were obtained from the paraffin blocks and cuts were taken to lysozyme slides. After deparaffinization and rehydration, sections were stained with immunohistochemistry for detection of FSHR and LHR expressions. After treating with H\(_2\)O\(_2\) for the elimination of endogenous peroxidase activity, sections were covered with blocking solution for 20 min to reduce nonspecific antibody binding. Later, sections were incubated overnight at 4 °C with anti-rabbit FSHR (1:250, 22665-1-AP, Proteintech, rabbit polyclonal) and LHR (1:250, NLS1436, Novus Biologicals, rabbit polyclonal) primary antibodies. Samples were then rinsed with PBS and incubated with ImmPRESS-HRP anti-rabbit IgG (peroxidase) reagent (NC9027342, Vector Laboratories) for 30 min and incubated 5 minutes with DAB for colour development. Harris hematoxylin was used for counterstaining. The intensity and localization of FSHR and LHR expressions were assessed by two blinded observers, and five different areas per slide were scored with an H-scoring system: 0: no immunoreaction; 1+: weak immunoreaction; 2+: moderate immunoreaction; 3+: strong immunoreaction. The percentage of cells at different staining intensities was determined by visual assessment, with the score calculated using the formula 1x (% of 1+ cells) + 2x (% of 2+ cells) + 3x (% of 3+ cells) (Mazieres et al., 2013). All micrographs were taken with a microscope (Nikon 80i, JP).

**Statistical analysis**

FSHR and LHR expressions were investigated by using the non-parametric Kruskal Wallis test. The Mann-Whitney U test was used to analyze statistical significance between the two groups (p<0.05). Statistical analysis of the study was performed using SPSS 23.0 (IBM).

**RESULTS**

The effects of the different doses of Ca\(^{2+}\) and AP, and the use of phytase on FSHR and LHR expressions in the ovaries of laying hens are presented in Tables 2 and 3, and Figures 1 and 2.

**Table 2. H-scores of follicle stimulating hormone receptor (FSHR) immunoreactivity after Ca\(^{2+}\) and available phosphorus (AP) variable diet and phytase application.**

<table>
<thead>
<tr>
<th>Groups</th>
<th>Oocyte (mean±SE)</th>
<th>Vitellus (mean±SE)</th>
<th>Granulosa/ Theca Cells (mean±SE)</th>
<th>Interstitial Cells (mean±SE)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(n=10 each)</td>
<td>(mean±SE)</td>
<td>(mean±SE)</td>
<td>(mean±SE)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ca+AP</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phy-</td>
<td>2.00±0.13(^{a,b})</td>
<td>1.40±0.16(^{a})</td>
<td>1.90±0.18(^{a})</td>
<td>2.60±0.16(^{a,b})</td>
</tr>
<tr>
<td>CP</td>
<td>1.90±0.28*(^{b})</td>
<td>1.70±0.15(^{a})</td>
<td>2.20±0.20(^{a})</td>
<td>2.30±0.15(^{b})</td>
</tr>
<tr>
<td>MP</td>
<td>2.50±0.17*(^{a})</td>
<td>1.60±0.22(^{b})</td>
<td>2.70±0.10(^{a})</td>
<td>2.80±0.13(^{a})</td>
</tr>
<tr>
<td>Ca+low AP</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phy-</td>
<td>1.40±0.27*(^{a})</td>
<td>1.50±0.22(^{a})</td>
<td>1.90±0.18(^{a})</td>
<td>2.40±0.27(^{a,b})</td>
</tr>
<tr>
<td>CP</td>
<td>2.90±0.10*(^{a})</td>
<td>2.60±0.16(^{a})</td>
<td>2.10±0.10(^{a})</td>
<td>2.90±0.10(^{a})</td>
</tr>
<tr>
<td>MP</td>
<td>3.00±0.01*(^{a})</td>
<td>3.00±0.01*(^{a})</td>
<td>2.90±0.15(^{a})</td>
<td>2.90±0.10(^{a})</td>
</tr>
<tr>
<td>Low Ca+low AP</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phy-</td>
<td>1.10±0.23*(^{a})</td>
<td>1.40±0.22(^{a})</td>
<td>1.90±0.18(^{a,b})</td>
<td>2.10±0.17(^{a,b})</td>
</tr>
<tr>
<td>CP</td>
<td>2.50±0.22*(^{a})</td>
<td>1.70±0.21*(^{a,b})</td>
<td>2.10±0.18(^{a,b})</td>
<td>2.60±0.16(^{a,b})</td>
</tr>
<tr>
<td>MP</td>
<td>2.90±0.10*(^{a})</td>
<td>1.80±0.13*(^{a,b})</td>
<td>2.20±0.20*(^{a,b})</td>
<td>2.50±0.18*(^{a,b})</td>
</tr>
</tbody>
</table>

\(^{a,b,c}\); express the significant difference between subgroups in each main group; \(^{a,b}\); express the significant difference within the subgroups themselves, p<0.05.

Ca: Calcium, AP: Available phosphorus, Phy-: Phytase not added, CP: Commercial phytase, MP: Microbial phytase
Table 3. H-scores of luteinizing hormone receptor (LHR) immunoreactivity after Ca\(^{2+}\) and available phosphorus (AP) variable diet and phytase application.

<table>
<thead>
<tr>
<th>Groups</th>
<th>Oocyte (mean±SE)</th>
<th>Vitellus (mean±SE)</th>
<th>Granulosa/ Theca Cells (mean±SE)</th>
<th>Interstitial Cells (mean±SE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ca+AP</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phy-</td>
<td>1.20±0.32(^{b,c}),AB</td>
<td>1.80±0.13(^{a,B})</td>
<td>1.80±0.29(^{bc,A})</td>
<td>1.20±0.13(^{b,AB})</td>
</tr>
<tr>
<td>CP</td>
<td>1.60±0.16(^{b,c}),C,BC</td>
<td>2.20±0.13(^{BC})</td>
<td>1.80±0.29(^{b,a,B})</td>
<td>1.50±0.17(^{c,AB})</td>
</tr>
<tr>
<td>MP</td>
<td>1.90±0.28(^{b,c}),A</td>
<td>1.90±0.31(^{b,A})</td>
<td>2.20±0.20(^{b,b,B})</td>
<td>1.70±0.15(^{a-A})</td>
</tr>
<tr>
<td>Ca+low AP</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phy-</td>
<td>1.00±0.26(^{b,AB})</td>
<td>2.70±0.15(^{b,A})</td>
<td>2.70±0.15(^{a,B})</td>
<td>1.90±0.10(^{a-A})</td>
</tr>
<tr>
<td>CP</td>
<td>2.60±0.16(^{b,c})A</td>
<td>2.70±0.15(^{b,A})</td>
<td>2.60±0.16(^{b,a,A})</td>
<td>1.70±0.15(^{a,A})</td>
</tr>
<tr>
<td>MP</td>
<td>2.60±0.16(^{b,c})A</td>
<td>2.70±0.15(^{b,A})</td>
<td>2.60±0.16(^{b,a,A})</td>
<td>1.70±0.15(^{a,A})</td>
</tr>
<tr>
<td>Low Ca+low AP</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phy-</td>
<td>0.90±0.23(^{c,BC})</td>
<td>1.90±0.30(^{b,B})</td>
<td>2.00±0.15(^{b,b,A})</td>
<td>0.60±0.16(^{c,BC})</td>
</tr>
<tr>
<td>CP</td>
<td>2.00±0.21(^{b,BC})</td>
<td>1.10±0.23(^{a,B})</td>
<td>1.90±0.23(^{b,b,B})</td>
<td>1.00±0.26(^{b,b,B})</td>
</tr>
<tr>
<td>MP</td>
<td>2.60±0.16(^{b,c})A</td>
<td>2.40±0.22(^{b,BC})</td>
<td>2.40±0.22(^{b,b,B})</td>
<td>0.80±0.20(^{b,b,B})</td>
</tr>
</tbody>
</table>

\(a, b, c\); express the significant difference between subgroups in each main group; \(A, B, C\); express the significant difference within the subgroups themselves, \(p<0.05\).

Ca: Calcium, AP: Available phosphorus, Phy-: Phytase not added, CP: Commercial phytase, MP: Microbial phytase.

Figure 1. H-scores of follicle stimulating hormone receptor (FSHR)(A) and luteinizing hormone receptor (LHR)(B) expressions after Ca\(^{2+}\) and available phosphorus (AP) variable diet and phytase application. Statistical differences among the groups are given in Table 4 and 5. Ca: Calcium; AP: Available phosphorus; Phy-: Phytase not added; CP: Commercial phytase; MP: Microbial phytase.
Figure 2. Follicle stimulating hormone receptor (FSHR)(A-E) and luteinizing hormone receptor (LHR)(F-J) immunohistochemistry results. Granulosa/theca cells, oocyte, vitellus, and interstitial cells are labeled with arrow, plus, arrowhead, and star, respectively. (A) Ca+AP+MP; (B) Ca+low AP+CP; (C) Ca+low AP+MP; (D) low Ca+low AP+Phy-; (E) low Ca+low AP+MP; (F) Ca+AP+MP; (G) Ca+low AP+CP; (H) Ca+low AP+MP; (I) low Ca+low AP+CP; (J) low Ca+low AP+MP, where Ca: Calcium; AP: Available phosphorus; Phy-: Phytase not added; CP: Commercial phytase; MP: Microbial phytase. Bars= 100 µm.
Expression of FSHR was observed in the cell membrane of the granulosa/theca cells, oocyte, vitel-
lus, and interstitial cells in different growing stages of the ovarian follicles (Fig. 2A-E). When the ratio
between Ca and AP increased (Ca+low AP group), the severity of the FSHR expression in oocyte, vitel-
lus, and granulosa/theca cells increased; no increase was observed in the interstitial cells (Fig. 2B, 2C).
The FSHR expression decreased when chickens were fed with low doses of either Ca or AP (Fig. 2D). The
FSHR expression increased after phytase administration, especially the MP (Fig. 2E). The strongest FSHR
expression was observed in the ovarian components after feeding chickens with standard Ca and low AP
diet group and with MP (Fig. 1, Fig. 2C, Table 2).

Expression of LHR was observed in the cytosol of the oocytes, vitellus, and granulosa/theca cells of
the follicles, and the interstitial cells (Fig 2F-J). The LHR immunoreactivity in theca cells increased af-
after feeding with standard Ca+low AP and MP (Fig 2H). Similar to FSHR expression, when the Ca and
AP were decreased, the LHR immunoreactivity was also less prominent (Fig 2I). After MP administration
in the low Ca and low AP diet group, the reaction of LHR increased (Fig 2J). Interstitial cells were slightly
stained for both FSHR and LHR. The statistical differences of FSHR and LHR expressions among the
groups are shown in Tables 4 and 5.

DISCUSSION

The hormones FSH and LH, which play an effect-
tive role in folliculogenesis, steroidogenesis, and ovu-
lation in the ovary, act through their receptors FSHR
and LHR (Liu et al., 2019). In the literature, there are
studies about the mRNA expressions of FSHR and
LHR in poultry ovaries (Hu et al., 2021; Liu et al.,
2007), but the localization of these receptors has not
been investigated so far. In this study, we investigated
the FSHR and LHR expressions in ovaries under the
effects of different concentrations of Ca and P, and
newly isolated MP.

In many species, it is known that FSH acts on the
granulosa cells of growing follicles, while LH acts on
theca cells of large antral follicles (Chen et al., 2018).
However, the results of recent studies have demon-
strated that FSHR and LHR can be localized also in
other areas (oocyte, blood vessels, interstitial cells) of
ovaries (Burns et al. 2001; Meduri et al., 2002). Medu-
ri et al. (2002) demonstrated the direct effect of FSH
on oocyte development by observing the expression
of FSHR in human and porcine oocytes. In the same
study, LH expression was not observed in the oocyte
of the follicle at any developmental stage (Meduri et
al., 2002). Unlike Meduri et al. (2002), we observed
expression of both FSHR and LHR in oocytes in our
study. In a study performed in weaned gilts, authors
have demonstrated LHR expression in oocytes, and
they suggested that the expression of FSHR and LHR
in oocytes is important for activating the intracellular
steroidogenic signalling pathway (Wan et al., 2021).
Some researchers have proposed that the FSHR and
LHR genes have a key regulative role during vitello-
genesis in chub mackerel fishes (Nyuji et al., 2013).
Similarly, we observed FSHR and LHR expressions
in the vitellus of the follicles in our study.

Phytase is frequently added to poultry diets to
increase P utilization (Um and Paik, 1999). This en-
zyme enhances the reproductive performance and egg
quality characteristics (Saheb et al., 2018; Shet et al.,
2018). In our study, FSHR and LHR were more in-
tensely expressed in granulosa/theca cells and oocytes
in the groups supplemented with MP and CP com-
pared to the group without phytase. There was incon-
sistency between the phytase-untreated and -treated
groups regarding the FSHR and LHR expressions in
the interstitial cells and vitellus. Similar inconsist-
sencies about the effect of additional phytase have been
reported also in other studies. While the addition of
250 and 300 FTU/kg phytase to diets with low levels
of AP was suggested to improve feed intake and egg
mass layers by some researchers (Jalal and Scheidel-
er, 2001), no effect was observed by others (Zyla et
al., 2011; Tischler et al., 2015; Shet et al., 2018). In
a study performed using very high levels of phytase
(5000 FTU/kg) compared to other studies, Saleh et al.
(2021) demonstrated improved eggshell quality and
yolk cholesterol level in a 30% less AP diet.

Formulating proper ratios of Ca$^{2+}$ and AP in the
diet is crucial on the reproductive performance para-
 meters (Lim et al., 2003; Liu et al., 2007; Ziaei et
al., 2009). Egg production was completely stopped
in diets with Ca$^{2+}$ levels below 0.5 g/kg because Ca$^{2+}$
is needed for gonadotropin (especially LH) synthesis
from the pituitary (Gilbert et al., 1981). The Ca$^{2+}$
and AP content affected the FSHR and LHR immunoreac-
tivities in our study. Strong FSHR and LHR staining
were seen in the standard Ca$^{2+}$ and low AP groups,
whereas in the low Ca$^{2+}$ and AP diet group, the immu-
nostainings for both receptors were slight. Addition of
MP to the diets enhanced the signal in all groups sug-
gesting that additional phytase increases the FSHR and LHR expressions in ovaries, even in diets with insufficient Ca\(^{2+}\) and P levels.

**CONCLUSION**

In conclusion, in this study, FSHR and LHR immunoreactivities were shown for the first time in granulosa/theca, oocyte, vitellus, and interstitial cells of laying hens. The strongest FSHR and LHR expressions were observed in standard Ca\(^{2+}\) and low AP diet supplemented with a newly isolated MP source.

**ACKNOWLEDGMENTS**

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**CONFLICT OF INTEREST**

The authors declare no conflict of interest.

**REFERENCES**


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